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Research Article

Profit Maximization for Waste Furniture Recycled in Taiwan Using Cradle-to-Cradle Production Programming

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This study proposes the use of cradle-to-cradle production programming for waste furniture and aims to achieve optimal efficiency by reusing waste furniture and maximizing the corresponding benefits so that the furniture industry is in line with cradle-to-cradle manufacturing. This study is increasingly important to manage products through a comprehensive green reverse logistics system that consists of three procedures, i.e., recycling, reuse, and remanufacturing of waste items. This study proposes a mathematical formula to establish a cradle-to-cradle production programming model for waste furniture. The fuzzy set theory is used to define the attributes that reflect production and market demands such as degree of damage, technical feasibility, market demands, environmental protection laws and regulations, and environmental performance. In addition, particle swarm optimization is adopted to ascertain the optimal profit from waste furniture sales. Through situational simulations and analyses, the fuzzy set information from Taiwan, Germany, and China is compared. The result reveals that the qualitative information proposed has a significant impact on the profit of waste furniture reuse. The production model can effectively assist in the production programming of waste furniture, thereby optimizing profit for cradle-to-cradle production planning.

1. Introduction

Taiwan introduced the Resource Recycling Act, which aims to establish proper disposal of waste products, to advocate complete recycling and reuse of resources, to save natural resources, to reduce environmental loads, and to establish a sustainable society. Subsequently, the Taiwan Environmental Protection Administration [1, 2] initiated the Bulky Waste Recycling and Reuse program and assisted counties and cities in its implementation in 2003. In March 2004, the TEPA initiated a garbage classification program, the goal being zero waste disposal. The cleanup operation for general household waste was driven by zero waste and waste reduction guidelines in source and resource recycling. The government continued the implementation of the Bulky Waste Recycling and Reuse program with its incorporation into the 2007–2012 Recycling Program for General Waste Resources. The cradle-to-cradle (C2C) concept for industrial products was globally acknowledged as a replacement for the cradle-to-grave concept due to the increasing awareness of the need for environmental protection [3–5]. The C2C concept meant that the waste from certain products would serve as the raw material of newly produced items, and that step in the manufacturing process would comply with environmental protection laws and regulations to reduce resource consumption and harmful emissions. In this way, sustainability could be achieved [6–8]. Moreover, customers would now pay closer attention to whether products that were at the end of their useful life were to be disposed of, recycled, or reused due to environmental protection awareness. It has been discarded "wastes" can be recycled, reduced, and reused (3Rs) and be more valuable [9–11].

In the literature, Fujii et al. [9] discussed the demand for recycled products, economic conditions, weight reduction, product reuse, and quantity and types of competitive recycled products; they developed a social system for customer purchases that influence waste generation. Pandey et al. [12] promoted reuse and recycling practices in reducing wastes and analyzed the practices that help in reducing the generation of waste. Tseng et al. [11] indicated that there was interdependence and interrelationships among the attributes, along with a lack of operational, data-driven, and optimization solutions in supply chain networks to optimize efficiency. Tam et al. [13] proposed waste materials needed to be efficiently returned for production, and the time-tested processes of reuse, recovery, and recycling (3Rs) were essential. The attributes were usually developed from qualitative information, and quantitative data were used in decision-making. However, prior studies did not explain how the attributes worked together to enhance the demand for recycled products, and such studies ignored the way the attributes were qualitative in measure and used only quantitative data [4, 14, 15]. In addition, there was a need to analyze the 3Rs in the optimization solution.

However, bulky waste is difficult to collect and remove regularly. There is no complete recycling system, and the resources are not used effectively. With the promotion of relevant recycling programs, bulky waste, such as waste furniture that still has value, is repaired and reused. In this way, the bulky waste, as well as the environmental loads, can be effectively reduced, an effect which is conducive to the goal of zero waste disposal. The fuzzy set theory deals with qualitative information. It is arguable that bulky waste is a way to generate profit in the value chain [8, 16, 17]. Hence, for this study, production programming is expected for waste furniture so that the maximum reuse rate can be achieved. Therefore, this study aims to establish the model of reusing the waste furniture to obtain the maximum profit from waste product sales. This study has established the C2C recycling production planning model for waste furniture through a mathematical model. It is hoped that, with this model, waste furniture is effectively recycled and reused, recycling profit can be maximized, and optimal remanufacturing volume is obtained [18]. In addition, this study has provided situational simulations to verify the optimality of the model.

This study focuses on waste furniture recycling, and remanufacturing the furniture through recycling centers under the TEPA jurisdiction includes the cleaning teams that are responsible for removing and transporting waste furniture as well as the processing centers in which waste furniture is processed for reuse and remanufacturing. In the processing centers, reusable waste furniture is repaired, reusable parts are disassembled, and the parts beyond repair are crushed. This study takes into account the following costs: recycling cost, repair cost, disassembly cost, and crushing cost. The study does not consider the inventory cost. For the purchase cost, only the cost of new raw materials is taken into consideration.

The rest of this study is organized as follows: Section 2 is the theoretical background; method and industrial background are described in Section 3; Section 4 presents the results and the sensitivity analysis; lastly, the concluding remarks are discussed.

2. Literature Review

Sustainable development was first proposed by the World Commission on Environment and Development of the United Nations (1987). This proposal aimed to meet the needs of the present without compromising the ability of future generations to meet their own needs [19, 20]. In addition, Braat [21] proposed that sustainable development should include three principles, i.e., fairness, sustainability, and commonality, and economic development should be pursued based on the sustainable development of the ecological environment and promoted around the world [10, 22, 23]. Wong et al. [24] used sustainable development assessment to achieve social, environmental, and economic benefits and created an assessment model using qualitative information and quantitative data. However, sustainable development included recycling end-of-life products, while the planning and performance evaluation of recycling end-of-life product plans ensured that collected recyclable materials, as well as the assessment of environmental impacts, did not increase those impacts. Xu et al. [25] explored sustainable development driving forces to assess sustainability in China. In addition, the assessment of social, environmental, and economic benefits was performed using qualitative and quantitative measures. Prior studies were usually lacking in attributes analysis.

Lin et al. [3] highlighted the clean cycle strategy and presented better recycled product qualities and less dissipation of hazardous substances during recycled product usage. This study ignored CO_2 emissions during the recycled production process. Being free of hazardous substances was always required in the new production manufacturing process. Nurjanni et al. [26] presented a multiobjective optimization mathematical model to reduce costs and minimize environmental pollution through a trade-off between financial and environmental issues. However, the business model is needed to balance the social, economic, and environmental impacts. Sultan et al. [27] presented the mixture of materials and the separation of materials that make up a product as a model of the desirability of recycling end-of-life products. Lin et al. [4] developed a cradle-to-cradle fuzzy recycling production planning model for a green product using the failure mode and effects analysis technique, along with the Taguchi experimental design method. However, the performance evaluation system had to involve the qualitative information and quantitative data to create the optimal recycled production plan and estimate the attributes related to the 3Rs.

3. Method

This section includes the 3Rs on waste furniture and the proposed method.

3.1. 3Rs on Waste Furniture. The data updated by the TEPA in 2012 about the condition of recycling bulky waste and waste furniture collated the current situation as follows: (1) the method of cleaning up waste furniture includes having those who generate the waste (most of them) notifying the executive authorities (cleaning teams) to remove it and pays the private sectors to remove it. After the waste furniture is recycled, most of it is manually sorted, and a small part of it is sorted by machine. The damaged furniture is often resold to the public for reuse after it has been repaired by professionals. (2) Most waste furniture can be reused. However, due to its large size, collecting and removing the furniture at regular intervals is difficult. In addition, a complete recycling system is rarely seen in Taiwan.

Therefore, the waste furniture is mostly incinerated or buried. The resources are not used effectively, and even the environment has been affected by the means of waste disposal [28, 29]. (3) Waste furniture can reenter the market as products after being properly repaired, while recycled resources from waste furniture can reenter the market as raw materials, which reduces the environmental loads by lowering the amount of waste for incineration or landfill disposal. The category, as well as the worn-out condition of the abandoned furniture, determines the best way to reuse it, including repair, disassembly, and crushing. The first step to reduce waste is to extend the useful life of the furniture by repairing the damaged item and reusing it. Different types of furniture can be repaired after cost performance is considered from the perspectives of the degree of damage and the ease of repair.

3.2. Proposed Approach. This study uses particle swarm optimization (PSO) to find solutions. The advantages of using PSO are that only a few parameters need to be adjusted and that it can be used to solve most optimization problems. The PSO is a heuristic algorithm of swarm intelligence and observes how a flock of birds flies and hunts for food. It simulates the flock of bird's method of communication to find the optimal solution [30–32]. Furthermore, a mechanism of evolutionary computation is established according to the best flight of a single bird and that of a flock of birds. Dimension d $(1 \leq d \leq D)$ of a particle updates its own speed and position with the following equation when the particle best (pbest) and the global best (gbest) are found for each generation:

$$\begin{aligned} v_{id}(t+1) &= w \cdot v_{id}(t) + c_1 \cdot r_1 \cdot \left[p_{id} - x_{id}(t)\right] \\ &\quad + c_2 \cdot r_2 \cdot \left[p_{gd} - x_{id}(t)\right], \\ x_{id}(t+1) &= x_{id}(t) + v_{id}(t+1), \end{aligned} \tag{1}$$

where $v_{id}(t+1)$ is the new speed of particle i, $v_{id}(t)$ is the original speed of particle i, w is the inertia weight, c_1 and c_2 are learning factors, r_1 and r_2 random numbers between 0 and 1, $\chi_{id}(t+1)$ is the new position of particle i, $\chi_{id}(t)$ is the original position of particle i, p_{id} is the individual best position of particle i (pbest), and p_{gd} is the global best position (gbest).

3.3. C2C Waste Furniture Manufacturing Process. This study formulates C2C programming for manufacturing recycled waste furniture. It mainly focuses on the remanufacturing of waste furniture and reproduction, with the crushed waste furniture as raw materials. This study aims to establish a green production model that maximizes benefits, with the goal of achieving zero waste during the disposal of waste furniture for reuse. The C2C process for waste furniture is shown in Figure 1. This study discusses the waste furniture C2C production process after waste furniture is produced and removed.

3.4. The Establishment of the Model. Parameter descriptions are as follows:

(1) i: the batch of waste furniture being recycled for remanufacturing, $i = 1, \ldots, N$

(2) $\tilde{a}_i\tilde{d}$: the fuzzy information for waste furniture production planning

(3) $\tilde{u}_{i,}\tilde{v}_i$: the fuzzy information for crushing waste furniture

Decision variables are as follows:

(4) X_i: the proportion of waste furniture Batch i made into remanufactured furniture

(5) D_i: the proportion of waste furniture Batch i disassembled into reusable raw materials

(6) U_i: the proportion of waste furniture Batch i made into coarsely crushed materials

(7) V_i: the proportion of waste furniture Batch i made into finely crushed materials

The schematic diagram shown in Figure 2 includes the removal and reuse of waste wood furniture; the reusable items include remanufactured furniture, coarsely crushed materials, and finely crushed materials.

3.5. Mathematical Model

3.5.1. Construct an Objective Function. The profit on recycled waste furniture for reuse = remanufactured furniture sales revenue + crushed material sales revenue−(recycling waste furniture cost + the cost of disassembling waste furniture into reusable materials + repair cost for

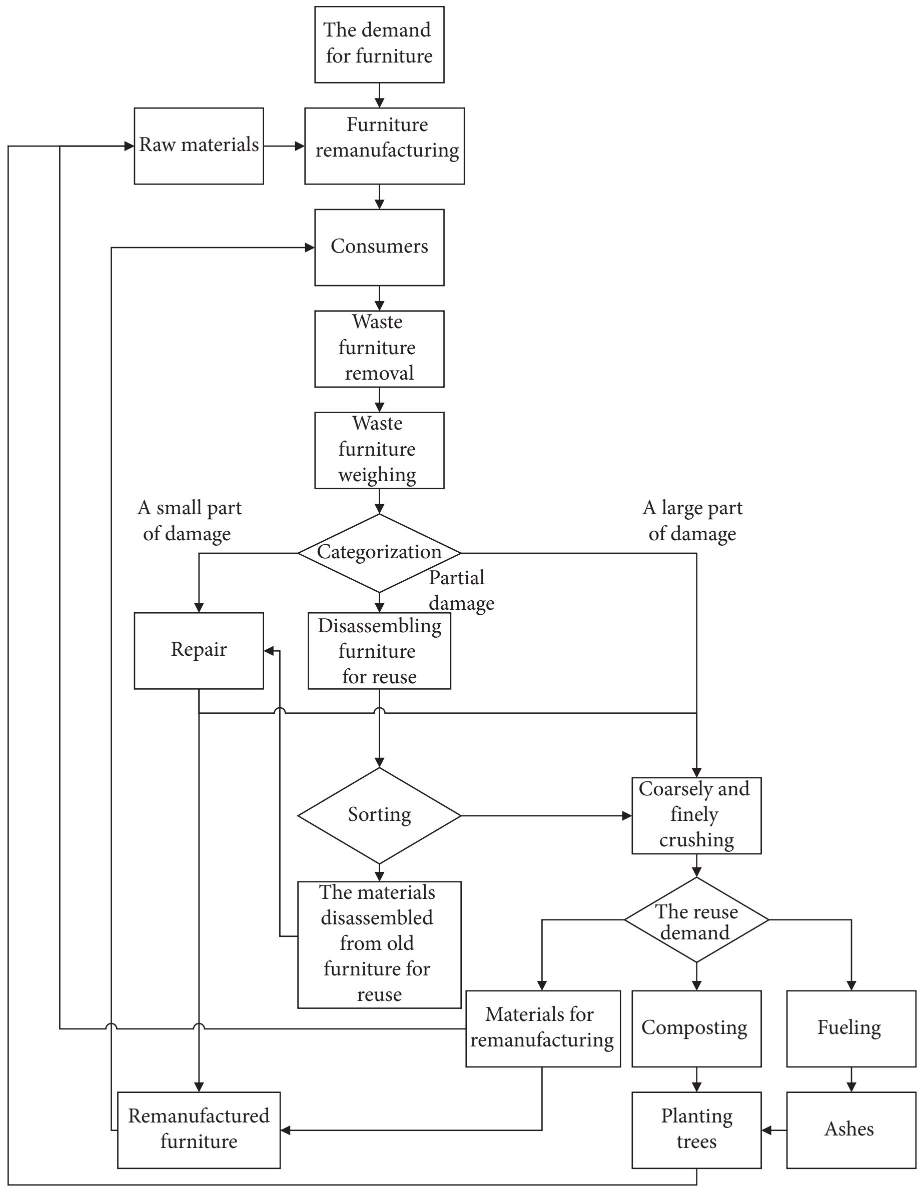

Figure 1: The C2C production programming for waste furniture.

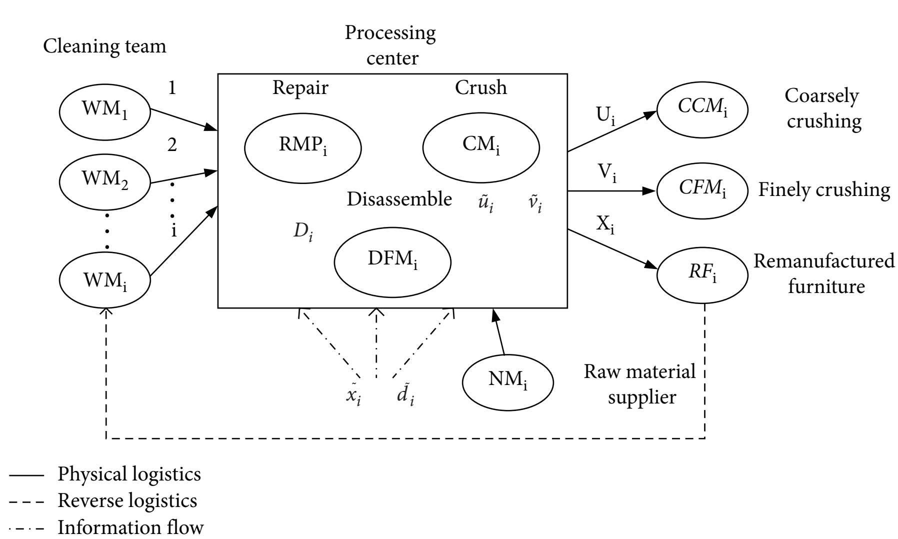

Figure 2: The schematic diagram for the production programming model.

remanufactured furniture + coarsely crushing cost of waste furniture + finely crushing cost of waste furniture):

$$\tilde{Z} = \sum_{i=1}^{N} PSG_i + \sum_{i=1}^{N} RSU_i - \sum_{i=1}^{N} \left(RC_i + DP\,C_i + PC_i + BCC_i + BFC_i \right). \tag{2}$$

Explanation of the Objective Function.

(1) Remanufactured Furniture Sales Revenue. The remanufactured furniture sales revenue = the amount of remanufactured furniture × the unit price of remanufactured furniture:

$$\begin{aligned} \sum_{i=1}^{N} PSG_i &= \sum_{i=1}^{N} \left(\mathrm{RF}_i \times \mathrm{FP}_i \right), \\ \mathrm{RF}_i &= \left(\mathrm{WM}_i \times \tilde{X}_i \right) + \mathrm{NM}_i. \end{aligned} \tag{3}$$

The total amount of waste furniture that has been repaired = the total amount of recycled waste furniture of Batch i WM_i × the proportion of recycled furniture made into remanufactured furniture $\tilde{X}_i$ + the amount of new materials invested in remanufactured furniture [33–35]. The operational rule of fuzzy numbers and the application of membership functions propose the use of the fuzzy theory to solve uncertainty and ambiguity in the real world.

$\tilde{x}_i$ and $\tilde{d}_i$ are the fuzzy information of waste furniture production programming. After calculating the fuzzy information, the proportion of recycled waste furniture made into remanufactured furniture $\tilde{X}_i$ (a fuzzy value) and the reuse rate of disassembled waste furniture $\tilde{D}_i$ (a fuzzy value) can be obtained. The calculation of fuzzy information will be further introduced in Section 3.4.

(2) The Sales Revenue of Crushed Waste Furniture. The sales revenue of crushed waste furniture = coarsely crushed materials from waste furniture × the unit price of the coarsely crushed materials + finely crushed materials from waste furniture × the unit price of the finely crushed materials:

$$\begin{aligned} \sum_{i=1}^{N} RSU_i &= \sum_{i=1}^{N} \left(CCM_i \times CMP_i + FCM_i \times FMP_i \right), \\ CCM_i &= CM_i \times \tilde{U}_i, \\ FCM_i &= CM_i \times \tilde{V}_i. \end{aligned} \tag{4}$$

The total amount of coarsely crushed materials from waste furniture = the total amount of recycled furniture of the i^{th} batch WM_i × the proportion of the waste furniture that has been coarsely crushed $\tilde{U}_i$.

The total amount of finely crushed materials from waste furniture = the total amount of recycled furniture of the i^{th} batch WM_i × the proportion of the waste furniture that has been finely crushed $\tilde{V}_i$.

$\tilde{u}_i$ and $\tilde{v}_i$ are the fuzzy information of waste furniture production programming. After calculating the fuzzy information, the fuzzy values for $\tilde{U}_i$ and $\tilde{V}_i$ can be obtained. The calculation of fuzzy information will be further introduced in Section 3.4.

(3) The Cost of Recycling Waste Furniture. The cost of recycling waste furniture = the amount of waste furniture that the cleaning team has removed and transported × the unit price of recycling waste furniture:

$$\sum_{i=1}^{N} \mathrm{RC}_i = \sum_{i=1}^{N} \left(\mathrm{WM}_i \times \mathrm{CC} \right). \tag{5}$$

(4) The Cost of Disassembling Waste Furniture into Reusable Materials. The cost of disassembling waste furniture into reusable materials = the amount of waste furniture that has been disassembled for reuse × the unit price of the disassembled reusable materials:

$$\begin{aligned} \sum_{i=1}^{N} DP\,D_i &= \sum_{i=1}^{N} \left(DF\,M_i \times \mathrm{DC} \right), \\ DF\,M_i &= \mathrm{WM}_i \times \tilde{D}_i. \end{aligned} \tag{6}$$

The waste furniture that is beyond repair but can still be reused is disassembled into reusable materials. The amount of reclaimed materials from disassembled waste furniture = the total amount of recycled waste furniture of Batch i_{WM_i} × the proportion of waste furniture disassembled for reuse $\tilde{D}_i$.

(5) The Cost of repairing Waste Furniture. The cost of repairing waste furniture = the amount of remanufactured furniture × the unit price of the remanufactured furniture + the new materials used for repairing waste furniture × the unit price of the new materials:

$$\sum_{i=1}^{N} DP\,C_i = \sum_{i=1}^{N} \left[\mathrm{RF}_i \times \mathrm{RC} + \left(\mathrm{NM}_i \times NMC \right) \right]. \tag{7}$$

The cost of repairing waste furniture primarily includes labor and the new materials used for repairing:RC represents the labor cost, NM_i represents the new materials used for repairing waste furniture, and NMC represents the unit price of the new materials.

(6) The Cost of Coarsely Crushing Waste Furniture for Reuse. The cost of coarsely crushing waste furniture for reuse = the amount of coarsely crushed materials × the unit price of coarsely crushing waste furniture:

$$\sum_{i=1}^{N} BCC_i = \sum_{i=1}^{N} (CCM_i \times CCC). \quad (8)$$

(7) The Cost of Finely Crushing Waste Furniture for Reuse. The cost of finely crushing waste furniture for reuse = the amount of finely crushed materials × the unit price of finely crushing waste furniture:

$$\sum_{i=1}^{N} BFC_i = \sum_{i=1}^{N} (FCM_i \times FCC). \quad (9)$$

3.5.2. Constraint. The constraints are explained as follows:

$$(\mathrm{RF}_i + DF\,M_i + CCM_i + FCM_i) \le \mathrm{TM}_i, \quad (10)$$

$$CCM_i + FCM_i \le \mathrm{CM}_i, \quad (11)$$

$$\widetilde{X}_i + \widetilde{D}_i + \widetilde{U}_i + \widetilde{V}_i \le 1, \quad (12)$$

$$\mathrm{WM}_i \times \widetilde{x}_i \le R \times \mathrm{RT}_i, \quad (13)$$

$$\mathrm{WM}_i \times \widetilde{y}_i \le Dl \times \mathrm{DT}_i, \quad (14)$$

$$\mathrm{WM}_i \times \widetilde{u}_i \le C \times \mathrm{CT}_i, \quad (15)$$

$$\mathrm{WM}_i \times \widetilde{v}_i \le F \times \mathrm{FT}_i, \quad (16)$$

$$\mathrm{TM}_i, \mathrm{WM}_i, \mathrm{RF}_i, DF\,M_i, \mathrm{CM}_i, CCM_i, FCM_i, \mathrm{NM}_i \ge 0, \quad (17)$$

$$0 \le x_i \le 1, 0 \le y_i \le 1, 0 \le u_i \le 1, 0 \le v_i \le 1. \quad (18)$$

(i) Constraint (10): the amount of remanufactured furniture, reusable parts disassembled from waste furniture, and crushed waste furniture shall not exceed the total amount of recycled waste furniture and new raw materials.
(ii) Constraint (11): the total amount of the materials from coarsely and finely crushed furniture is less than the total amount of crushed waste furniture.
(iii) Constraint (12): the total of the following: the proportion of recycled waste furniture that has been used in remanufacturing, the proportion of waste furniture that has been disassembled for reuse, and the proportion of waste furniture crushed for reuse should not exceed the overall proportion of recycled waste furniture, ≤ 1.
(iv) Constraint (13): the output of remanufactured furniture does not exceed the maximum repairable capacity of the remanufacturing center.
(v) Constraint (14): the amount of waste furniture disassembled for reuse does not exceed the maximum disassembling capacity of the remanufacturing center.
(vi) Constraint (15): the amount of coarsely crushed waste furniture does not exceed the maximum coarsely crushing capacity of the remanufacturing center.
(vii) Constraint (16): the amount of finely crushed waste furniture does not exceed the maximum finely crushing capacity of the remanufacturing center.
(viii) Constraint (17): the amount of each material must be greater than zero.
(ix) Constraint (18): the value of decision variables ranges between 0 and 1.

3.6. Establish a Mode for Computing Fuzzy Values

3.6.1. Establishment of Fuzzy Information $\widetilde{x}_i$ and $\widetilde{d}_i$. First, define the three inputs and establish the three membership functions:

(i) The membership function for the product damage degree is {almost damaged, quite worn-out, average, many reusable parts, reusable in whole}. The trigonometric function for it is $\mu_{\widetilde{x}}(a) = [0.45, 0.75]$.
(ii) The membership function for technical repair feasibility is {extremely low reparability, low reparability, average, high reparability, extremely high reparability}. The trigonometric function for this is $\mu_{\widetilde{x}}(t) = [0.45, 0.75]$.
(iii) The membership function for product market demand is {extremely low, relatively low, average, relatively high, extremely high}. The trigonometric function for this is $\mu_{\widetilde{x}}(m) = [0.25, 0.65]$.

$\widetilde{x}_i$ and $\widetilde{d}_i$ are the fuzzy production volume of remanufactured furniture under waste furniture production programming and the fuzzy amount of reusable raw materials disassembled from waste furniture, respectively. They are both affected by three fuzzy information factors: the degree of damage, the repair feasibility, and the market demand. Their fuzzy functions are as follows:

$$\tilde{x} = f\left(\mu_{\tilde{x}}(a), \mu_{\tilde{x}}(t), \mu_{\tilde{x}}(m)\right) = \begin{cases} 0, & \text{if } a < 0.45, \text{or } t < 0.45, \text{or } m < 0.25, \\ \dfrac{(a-0.45)(t-0.45)(m-0.25)}{0.036}, & \text{if } 0.75 > a \geq 0.45, \text{and } 0.75 > t \geq 0.45, \text{and } 0.65 > m \geq 0.25, \\ \dfrac{(a-0.45)(t-0.45)}{0.09}, & \text{if } 0.75 > a \geq 0.45, \text{and } 0.75 > t \geq 0.45, \text{and } m \geq 0.65, \\ \dfrac{(t-0.45)(m-0.25)}{0.12}, & \text{if } a \geq 0.75, \text{and } 0.75 > t \geq 0.45, \text{and } 0.65 > m \geq 0.25, \\ \dfrac{(a-0.45)(m-0.25)}{0.12}, & \text{if } 0.75 > a \geq 0.45, \text{and } t \geq 0.75, \text{and } 0.65 > m \geq 0.25, \\ \dfrac{t-0.45}{0.3}, & \text{if } a \geq 0.75, \text{and } 0.75 > t \geq 0.45, \text{and } m \geq 0.65, \\ \dfrac{a-0.45}{0.3}, & \text{if } 0.75 > a \geq 0.45, \text{and } t \geq 0.75, \text{and } m \geq 0.65, \\ \dfrac{m-0.25}{0.4}, & \text{if } a \geq 0.75, \text{and } t \geq 0.75, \text{and } 0.65 > m \geq 0.25, \\ 1, & \text{if } a \geq 0.75, \text{and } t \geq 0.75, \text{and } m \geq 0.65, \end{cases}$$

$$\tilde{d} = f\left(\mu_{\tilde{d}}(a), \mu_{\tilde{d}}(t), \mu_{\tilde{d}}(m)\right) = \begin{cases} 0, & \text{if } a < 0.45, \text{or } t < 0.45, \text{or } m < 0.25, \\ \dfrac{(a-0.45)(t-0.45)(m-0.25)}{0.036}, & \text{if } 0.75 > a \geq 0.45, \text{and } 0.75 > t \geq 0.45, \text{and } 0.65 > m \geq 0.25, \\ \dfrac{(a-0.45)(t-0.45)}{0.09}, & \text{if } 0.75 > a \geq 0.45, \text{and } 0.75 > t \geq 0.45, \text{and } m \geq 0.65, \\ \dfrac{(t-0.45)(m-0.25)}{0.12}, & \text{if } a \geq 0.75, \text{and } 0.75 > t \geq 0.45, \text{and } 0.65 > m \geq 0.25, \\ \dfrac{(a-0.45)(m-0.25)}{0.12}, & \text{if } 0.75 > a \geq 0.45, \text{and } t \geq 0.75, \text{and } 0.65 > m \geq 0.25, \\ \dfrac{t-0.45}{0.3}, & \text{if } a \geq 0.75, \text{and } 0.75 > t \geq 0.45, \text{and } m \geq 0.65, \\ \dfrac{a-0.45}{0.3}, & \text{if } 0.75 > a \geq 0.45, \text{and } t \geq 0.75, \text{and } m \geq 0.65, \\ \dfrac{m-0.25}{0.4}, & \text{if } a \geq 0.75, \text{and } t \geq 0.75, \text{and } 0.65 > m \geq 0.25, \\ 1, & \text{if } a \geq 0.75, \text{and } t \geq 0.75, \text{and } m \geq 0.65. \end{cases} \tag{19}$$

Calculation of fuzzy information $\tilde{x}_i$: this study proposes fuzzy evaluation values for remanufactured furniture in Taiwan: 3 for the product damage degree (ordinary), 4 for repair feasibility (high reparability), and 2 for product market demand (relatively low). Therefore, the fuzzy value of $\widetilde{x}_i$ is inferred as $\widetilde{x} = 0.105$:

$$\widetilde{x} = f\left(\mu_{\widetilde{x}}(a), \mu_{\widetilde{x}}(t), \mu_{\widetilde{x}}(m)\right) = \frac{(0.6 - 0.45)(0.66 - 0.45)(0.37 - 0.25)}{0.036} = 0.105. \tag{20}$$

Calculation of fuzzy information $\widetilde{d}_i$: this study proposes fuzzy evaluation values for the materials disassembled from waste furniture: 2 for the product damage degree (quite worn-out), 2 for repair feasibility (low reparability), and 2 for market demand (relatively low). Therefore, the fuzzy value of $\widetilde{d}_i$ is inferred as $\widetilde{d} = 0.027$:

$$\widetilde{d} = f\left(\mu_{\widetilde{d}}(a), \mu_{\widetilde{d}}(t), \mu_{\widetilde{d}}(m)\right) = \frac{(0.54 - 0.45)(0.54 - 0.45)(0.37 - 0.25)}{0.036} = 0.027. \tag{21}$$

3.6.2. Establishment of Fuzzy Information $\widetilde{u}_i$ and $\widetilde{v}_i$. First, define the three fuzzy inputs as environmental protection laws and regulations, environmental performance indexes, and the product market demand:

(i) The membership function for environmental protection laws and regulations is {no relevant laws and regulations, low ratio, average, relatively high ratio, strict regulations}. The trigonometric function for it is $\mu_{\widetilde{u}}(p) = [0.35, 0.75]$.

(ii) The membership function for the environmental performance index is {extremely high impact index, relatively high impact index, average, relatively low impact index, extremely low impact index}. The trigonometric function for it is $\mu_{\widetilde{u}}(n) = [0.25, 0.75]$.

(iii) The membership function for the product market demand is {extremely low, relatively low, average, relatively high, extremely high}. The trigonometric function for it is $\mu_{\widetilde{u}}(m) = [0.45, 0.85]$.

The fuzzy functions for $\widetilde{u}_i$ and $\widetilde{v}_i$ are as follows:

$$\widetilde{u} = f\left(\mu_{\widetilde{u}}(p), \mu_{\widetilde{u}}(n), \mu_{\widetilde{u}}(m)\right. = \begin{cases} 0, & \text{if } p < 0.35, \text{ or } n < 0.25, \text{ or } m < 0.45, \\ \dfrac{(p - 0.35)(n - 0.25)(m - 0.45)}{0.08}, & \text{if } 0.75 > p \geq 0.35, \text{ and } 0.75 > n \geq 0.25, \text{ and } 0.85 > m \geq 0.45, \\ \dfrac{(p - 0.35)(n - 0.25)}{0.2}, & \text{if } 0.75 > p \geq 0.35, \text{ and } 0.75 > n \geq 0.25, \text{ and } m \geq 0.85, \\ \dfrac{(n - 0.25)(m - 0.45)}{0.2}, & \text{if } p \geq 0.75, \text{ and } 0.75 > n \geq 0.25, \text{ and } 0.85 > m \geq 0.45, \\ \dfrac{(p - 0.35)(m - 0.45)}{0.16}, & \text{if } 0.75 > p \geq 0.35, \text{ and } n \geq 0.75, \text{ and } 0.85 > m \geq 0.45, \\ \dfrac{n - 0.25}{0.5}, & \text{if } p \geq 0.75, \text{ and } 0.75 > n \geq 0.25, \text{ and } m \geq 0.85, \\ \dfrac{p - 0.35}{0.4}, & \text{if } 0.75 > p \geq 0.35, \text{ and } n \geq 0.75, \text{ and } m \geq 0.85, \\ \dfrac{m - 0.45}{0.4}, & \text{if } p \geq 0.75, \text{ and } n \geq 0.75, \text{ and } 0.85 > m \geq 0.45, \\ 1, & \text{if } p \geq 0.75, \text{ and } n \geq 0.75, \text{ and } m \geq 0.85. \end{cases}$$

$$\tilde{v} = f\left(\mu_{\tilde{v}}(p), \mu_{\tilde{v}}(n), \mu_{\tilde{v}}(m)\right) = \begin{cases} 0, \quad \text{if } p < 0.35, \text{ or } n < 0.25, \text{ or } m < 0.45, \\ \dfrac{(p-0.35)(n-0.25)(m-0.45)}{0.08}, \quad \text{if } 0.75 > p \geq 0.35, \text{ and } 0.75 > n \geq 0.25, \text{ and } 0.85 > m \geq 0.45, \\ \dfrac{(p-0.35)(n-0.25)}{0.2}, \quad \text{if } 0.75 > p \geq 0.35, \text{ and } 0.75 > n \geq 0.25, \text{ and } m \geq 0.85, \\ \dfrac{(n-0.25)(m-0.45)}{0.2}, \quad \text{if } p \geq 0.75, \text{ and } 0.75 > n \geq 0.25, \text{ and } 0.85 > m \geq 0.45, \\ \dfrac{(p-0.35)(m-0.45)}{0.16}, \quad \text{if } 0.75 > p \geq 0.35, \text{ and } n \geq 0.75, \text{ and } 0.85 > m \geq 0.45 \\ \dfrac{n-0.25}{0.5}, \quad \text{if } p \geq 0.75, \text{ and } 0.75 > n \geq 0.25, \text{ and } m \geq 0.85, \\ \dfrac{p-0.35}{0.4}, \quad \text{if } 0.75 > p \geq 0.35, \text{ and } n \geq 0.75, \text{ and } m \geq 0.85, \\ \dfrac{m-0.45}{0.4}, \quad \text{if } p \geq 0.75, \text{ and } n \geq 0.75, \text{ and } 0.85 > m \geq 0.45, \\ 1, \text{ if } p \geq 0.75, \text{ and } n \geq 0.75, \text{ and } m \geq 0.85. \end{cases} \tag{22}$$

Calculation of fuzzy information $\tilde{u}_i$: this study proposes fuzzy evaluation values for reusable materials from coarsely crushed furniture: 3 for environmental protection rules and regulations (ordinary), 3 for environmental performance index (average impact index), and 4 for product market demand (relatively high). Therefore, the fuzzy value of $\tilde{u}_i$ is inferred as $\tilde{u} = 0.18$:

$$\tilde{u} = f\left(\mu_{\tilde{u}}(p), \mu_{\tilde{u}}(n), \mu_{\tilde{u}}(m)\right) = \frac{(0.55-0.35)(0.55-0.25)(0.69-0.45)}{0.08} = 0.18. \tag{23}$$

Calculation of fuzzy information of $\tilde{v}_i$: this study proposes fuzzy evaluation values for reusable materials from finely crushed furniture: 3 for environmental protection rules and regulations (ordinary), 3 for the environmental performance index (average impact index), and 4 for product market demand (relatively high). Therefore, the fuzzy value of $\tilde{v}_i$ is inferred as $\tilde{v} = 0.18$:

$$\tilde{v} = f\left(\mu_{\tilde{v}}(p), \mu_{\tilde{v}}(n), \mu_{\tilde{v}}(m)\right) = \frac{(0.55-0.35)(0.55-0.25)(0.69-0.45)}{0.08} = 0.18. \tag{24}$$

3.6.3. Calculation of Fuzzy Values. The fuzzy value reflects the actual proportion of the waste furniture that was put to reuse [36]. There were a total of four fuzzy values in this study: the proportion of waste furniture used in repair $\widetilde{X}_i$, the proportion of waste furniture disassembled for reuse $\widetilde{D}_i$, the proportion of waste furniture coarsely crushed for reuse $\widetilde{U}_i$, and the proportion of waste furniture finely crushed for reuse $\widetilde{V}_i$. In the previous section, some fuzzy values were set to reflect the factors that influenced the production programming for waste furniture in Taiwan, and the membership functions that reflected the reuse of waste furniture through the fuzzy theory were established. Furthermore, it was necessary to calculate the corresponding proportions of the fuzzy information to the actual production programming for waste furniture so that relevant production planning could be performed. The proportions could be solved through the interpolation of fuzzy information: the fuzzy information between the known maximum and minimum proportions for production planning was substituted to determine the proportion. The equation sets x as the known number to determine the value of the linear function $y(x)$ and (x_1, y_1) and (x_2, y_2) as the maximum and minimum values, respectively:

$$\frac{(y - y_1)}{(x - x_1)} = \frac{(y_2 - y_1)}{(x_2 - x_1)}, \tag{25}$$

$$y = \left[\frac{(y_2 - y_1)}{(x_2 - x_1)}\right](x - x_1) + y_1. \tag{26}$$

The right side of equation (21) was the known x value and a constant. Accordingly, $y(x)$ could be obtained. Using the current situation in Taiwan as an example, from the expert opinions on fuzzy information, $\tilde{x}_i$ could be initially determined to be 0.105, $\tilde{d}_i = 0.036$, $\tilde{u}_i = 0.18$, and $\tilde{v}_i = 0.18$. Furthermore, $\tilde{X}_i$, $\tilde{D}_i$, $\tilde{U}_i$, and $\tilde{V}_i$ could be obtained through the interpolation method. The ratio of $\tilde{X}_i$ was between 10% and 30%, $\tilde{D}_i$ between 5% and 15%, $\tilde{U}_i$ between 35% and 45%, and $\tilde{V}_i$ between 35% and 45%. Through the interpolation method, the values for $\tilde{X}_i, \tilde{D}_i, \tilde{U}_i$, and $\tilde{V}_i$ were calculated as follows: $\tilde{X}_i = 0.121$, $\tilde{D}_i = 0.0536$, $\tilde{U}_i = 0.368$, and $\tilde{V}_i = 0.368$.

4. Results

This study made comparisons between simulated situations and conducted a performance evaluation and sensitivity analysis regarding the C2C production programming model for waste furniture. The simulated situations were written using the programming language in the Matlab R2010a version, and the simulation was executed on the ASUS A52J 2.13G CUP computer. For each situation, 30 groups of data were used to perform experiments.

4.1. Situation Analysis

4.1.1. Parameter Settings for the Waste Furniture Recycling Center

(i) The amount of recycled waste furniture: the waste furniture data collected from the center are shown in Table 1. For each batch, the output of remanufactured furniture, the amount of materials disassembled from waste furniture, and the amount of materials from crushed furniture were randomly chosen under the constraint of the maximum output. The simulation was performed through randomly generated numbers as the outputs.

(ii) Prices of various products: this study utilized the profits of a waste furniture remanufacturing center in 2006, which were from the sales of remanufactured furniture, when it calculated the unit price of remanufactured furniture. The annual sales revenue of remanufactured furniture was NTD 687,428 yuan, and the annual volume was 455.592 metric tons. Thus, the average revenue of a ton of remanufactured furniture was estimated to be NTD 1,508.868 yuan. The crushed materials could be divided into coarsely and finely crushed. Huang and Liu pointed out that the price of a metric ton of coarsely crushed material is NTD 700 yuan, while the price of finely crushed material is NTD 1,000 yuan.

Table 1: The amount of recycled waste furniture for each month.

Months	The amount (ton)
January	250.6
February	196.318
March	206.99
April	224.727
May	241.34
June	523.495
July	573.403
August	971.177

(iii) Various relevant costs: various costs were calculated based on the relevant cost data provided by the TEPA and Liu. The results were as follows: the average cost of waste furniture removal was NTD 166.67/metric ton, the average cost of repairing waste furniture was NTD 1,445.24/metric ton, the average cost of disassembling reusable parts from waste furniture was NTD 357.64/metric ton, the average cost of new materials was NTD 526.79/metric ton, the average cost of coarsely crushing waste furniture was NTD 400/metric ton, and the average cost of finely crushing waste furniture was NTD 600/metric ton.

(iv) Capacity limitations: this study assumed that there were four repairers, namely, two workers who disassembled waste furniture and two workers who operated the crusher. Each person worked 8 hours per day, and each month had 22 working days. Suppose, for example, it took the workers a month to process a batch; then, the workers would have 704 hours to repair each batch of waste furniture, 352 hours to disassemble it, and 352 hours to crush it, as shown in Table 2

4.1.2. Situational Simulation

(i) Taiwan has continuously promoted relevant recycling programs to encourage the recycling and reuse of waste furniture, such as the "Recycling Program for General Waste Resources." Due to the differences in urban and rural living habits in Taiwan, the discarded waste furniture collected from urban and rural areas is in different states. Taiwan currently has good repair techniques for waste furniture. However, the current demand for remanufactured furniture is still low.

(ii) Germany promulgated a decree on recycling waste wood, which is called the "Ordinance on the Management of Waste Wood." This decree prohibits the casual disposal of waste wood furniture [37, 38] and divides the recycled wood into five categories. There are different ways of processing and reusing waste wood, depending on the category.

(iii) China (Ching-Tao): with the increasing awareness of environmental protection, waste furniture and wood recycling agencies have been established

Table 2: The processing capacity for a unit of time.

Categories of time available	Time
The amount of repaired waste furniture for a unit of time	1,200 tons × 20 % = 240 tons 240 tons ÷ 704 = 0.34 tons/hour
The amount of disassembled waste furniture for a unit of time	1,200 tons × 10 % = 120 tons 120 tons ÷ 352 hours = 0.34 tons/hour
The amount of coarsely crushed waste furniture for a unit of time	1,200 tons × 30 % = 360 tons 360 tons ÷ 352 hours = 1.023 tons/hour
The amount of finely crushed waste furniture for a unit of time	1,200 tons × 30 % = 360 tons 360 tons ÷ 352 hours = 1.023 tons/hour

throughout China. There are also relevant rules and regulations in guiding the reuse of waste furniture and wood. Although there have been successful cases and policy support, overall, recycling waste furniture and wood has not been widely promoted in China.

The fuzzy information in this study varied with different situations, and the fuzzy information is collated, as shown in Table 3. The setting of parameters for the C2C waste furniture production programming model reflected the fact that Germany had the greatest potential of reusing waste furniture, followed by Taiwan and China.

Through the PSO, the maximum profit and the production planning amount of the 30 groups for each situation were obtained. The average maximum profit and planning production volume of the 30 groups for each situation are shown in Table 4.

4.2. Performance Evaluation

(i) Evaluation of statistical optimization: this evaluation was done to verify whether the programming model and algorithm proposed in this study were the optimal solution. The 30 entries of data for each situation were used for the statistical optimization evaluation. The Weibull++8 software was used as the analytical tool. The statistical optimization and the application of the software were described accordingly [39]. The proposed PSO had various combinations of the data which were consistent with Weber distribution in different situations. The test statistics were all less than P value as 0.01, and the solutions obtained by each combination fell within the optimal prediction interval. According to the analytical results above, the PSO proposed in this study had a good solution quality and performance under various environmental combinations. From the perspective of statistical optimization, it could also prove that the results obtained in this study were the optimal solution.

(ii) Analysis of simulation results: the simulation results were used to conduct ANOVA. The results showed that there were significant differences in profit from different situations under waste furniture C2C production programming. After that, multiple comparisons were made to discover the difference between situations in different degrees of fuzzy information. The comparison of the profits revealed that there were significant differences between each of the three situations, namely, Taiwan, Germany, and China (Ching-Tao City), since the P value was 0.01, which was less than 0.05. The aforesaid analysis indicated that different degrees of fuzzy information exerted an impact on the results of the C2C production programming. Germany, with its high productivity, obtained the maximum profit, while China (Ching-Tao City) received the lowest profit among the three situations. Thus, it was verified that, with the programming model, the maximum profit and production in different situations could be planned.

(iii) Sensitivity analysis: the current average unit cost for repairing furniture was NTD 1,445.42 yuan, which was expected to be reduced in the current situation. Therefore, this study discussed the sensitivity analysis of the repair cost of waste furniture and the cost of disassembling waste furniture for reusable materials. This study explored the changes when the repair cost was reduced from the original unit repair cost of NTD 1,445 yuan to 1,350 yuan, 1,250 yuan, 1,150 yuan, and 1,050 yuan, respectively. With the cost of repairing furniture decreasing, the sales obviously decreased, but there was no significant difference in the output of remanufactured furniture and the utilization of crushed materials. However, if more crushed materials from waste furniture were used, there would be a higher profit. Therefore, even if the waste furniture was damaged and even beyond repair, it should also be recycled, not only to reduce the amount of garbage but also to maximize the value of the resources.

4.3. Strategies to Improve the Benefits of Recycling Waste Furniture

4.3.1. Compulsory Procurement of the Authorities. Waste furniture recycling and reuse, along with the economic benefits of recycling and reusing waste furniture in Taiwan, has been constantly reviewed. Therefore, this study proposes the following strategies to improve the benefits from recycling waste furniture.

This study proposes that furniture procurement by the authorities should be regulated. The suggestion is that it becomes compulsory for the authorities to purchase remanufactured furniture, and their purchase volume would, therefore, reach 10% of their total annual purchases of furniture. According to data gathered from the Taiwan Buying Network, the total budget for furniture-related procurement by the authorities in Taiwan in July 2013 reached NTD 100,864,705 yuan. If 5% constitutes the revenue of remanufactured furniture sales, the amount is NTD 5,043,235 yuan. The average benefit earned from a ton of recycled furniture is estimated to be NTD 1,508.868 yuan, based on this study. To reap the profit of NTD 5,043,235 yuan, at least 3,342 tons of remanufactured furniture (5,043,235 divided by 1508.868) is needed in order to meet the demand of the authorities. According to the report on the implementation of the Bulky Waste Recycling and Reuse program by the Bureau of Environmental Inspection [40], it is feasible to produce at least 3,342 tons of remanufactured furniture per month. This strategy can provide the benefits as follows:

(i) Economic benefits: if it is compulsory for the authorities to purchase remanufactured furniture, the accumulated revenue will reach NTD 40,345,880 yuan in eight months. Compared with the estimated 431,470 yuan, which is eight months' profits of remanufactured furniture sales for a county, the amount is 93 times over. Obviously, the economic benefit is considerable.

(ii) Garbage reduction and increased reuse of waste furniture: the average profit of one ton of remanufactured furniture is estimated to be NTD 1,508.868 yuan. Therefore, to gain the profit of NTD 40,345,880 yuan from remanufactured furniture sales, the furniture industry needs to produce at least 26,736 tons of remanufactured furniture.

(iii) Carbon dioxide reduction: according to the report on recycling and reuse of waste furniture nationwide by the TEPA in July 2011, the recycling of waste wood per kilogram can reduce the emission of carbon dioxide by approximately 3.0 kg. In this study, 3,180.05 metric tons of waste furniture were recycled, thereby reducing 9,564,150 metric tons of carbon dioxide emissions. If it is compulsory for the authorities to buy remanufactured furniture, the amount of waste furniture to be repaired increases to 26,736 metric tons, reducing 80,208,000 metric tons of carbon dioxide emissions. Obviously, a greater environmental benefit can be achieved if the strategy is implemented (Table 5).

4.3.2. Subsidy Policy. This study suggests that a subsidy be provided to encourage the recycling of waste furniture. From the information compiled by the TEPA [1], the disposal cost for a ton of general garbage is NTD 1,811 yuan on average. If the NTD 1,811 yuan is applied to the recycling of waste furniture in order to increase the reuse of waste furniture, it is estimated that NTD 100 yuan can be used to subsidize the recycling of a waste table and 12 for the recycling of a waste chair. Suppose, for example, that the subsidy policy can increase 10% of recycled waste furniture; the potential benefits for implementing the subsidy policy are as follows:

(i) Economic benefit: in comparison with the expected profit of NTD 431,470 yuan for eight months' worth of remanufactured furniture in a county, the total revenue can reach NTD 473,589.3 yuan if the subsidy policy is implemented, with an additional profit of NTD 42,119.3 yuan. Evidently, the subsidy policy can further improve the economic benefit.

(ii) Carbon dioxide reduction: the recycling of waste wood per kilogram can reduce carbon dioxide emissions by approximately 3.0 kilograms. In this study, the amount of recycled waste furniture originally planned for 8 months in a county is 3,180.05 metric tons. The amount is expected to increase by 10% if the subsidy policy is implemented, i.e., 3,506.86 metric tons. Under this circumstance, the carbon dioxide emissions can be reduced by 10,520,580 metric tons and 956,430 tons more compared with the original reduction of 9,564,150 metric tons. Consequently, the subsidy policy is predicted to have an exceptional environmental protection benefit.

4.3.3. Corporate Social Responsibility. Table 6 presents the top 50 prestigious firms in Taiwan recycle their waste office furniture when they need replacements. In addition, no less than 1% of the newly procured office furniture should be remanufactured furniture. Through the implementation of this strategy, top firms can contribute their efforts to environmental protection. In this way, the amount of reclaimed waste furniture and the corresponding values is improved. If the remanufactured furniture bought by top firms reaches 1% of their newly procured equipment, the incurred benefits are as follows:

(i) Economic benefits: suppose 5% of their expenditure on office equipment is used to purchase remanufactured furniture; then, the firms spend NTD 33,640,790 yuan in one year. In this way, the profit from remanufactured furniture sales in eight months will reach NTD 22,427,193 yuan. This strategy is expected to increase profits 52 times. Evidently, this strategy has the potential to bring considerable economic profits compared with the original profit of NTD 431,470 yuan for a county in 8 months, as shown in Table 7.

(ii) Garbage reduction and improvement on recycling waste furniture: it is necessary to produce approximately 14,864 tons of remanufactured furniture for the firms to procure remanufactured furniture to reap a profit of NTD 22,427,193 yuan from the remanufactured furniture business. To this end, a large amount of waste furniture needs to be collected. Therefore, it is necessary to promote the recycling of waste furniture. In addition to top firms, the

Table 3: The comparison of fuzzy information in different situations.

Fuzzy information situations	$\tilde{x}_i$	$\tilde{d}_i$	$\tilde{u}_i$	$\tilde{v}_i$
Taiwan	0.105	0.027	0.18	0.18
Germany	0.252	0.0006	0.648	0.648
Ching-Tao, China	0.005	0.0013	0.003	0.003

Table 4: The results for the C2C waste furniture production programming in different situations.

Situations and results	Maximum profits	Output of remanufactured furniture	The output of coarsely crushed furniture	The output of finely crushed furniture
Taiwan	\$431,470	43.1	155.4	156.0
Germany	\$499,757	29.7	177.9	178.6
Ching-Tao, China	\$390,789	60.4	142.7	143.1

Unit: metric ton.

Table 5: The comparison of benefits between the current situation and strategy one.

Benefits	Current situation	Strategy 1	The improved benefit
The amount of recycled furniture	431,470	40,345,880	An increase in 10% recycled furniture
Profit	3,188.05	26,736	An increase in NTD 42,119.3 yuan
CO_2 reduction (ton)	9,564,150	80,208,000	A decrease in 956,430 tons of CO_2

Table 6: The comparison of benefits between the current situation and strategy two.

Benefits	Current situation	Strategy 2	The improved benefit
The amount of recycled furniture	3,188.05	3,506.86	An increase in 10% recycled furniture
Profit	431,470	473,589.3	An increase in NTD 42,119.3 yuan
CO_2 reduction (ton)	9,564,150	10,520,580	A decrease in 956,430 tons of CO_2

Table 7: The benefits of top firms purchasing remanufactured furniture.

	The most prestigious firms in Taiwan in 2012	The expenditure on office furniture and equipment in 2012	The profit from purchasing remanufactured products with the 1% cost of office equipment
1	Taiwan Semiconductor Manufacturing Firm	\$3,348,864,000	\$33,488,640
2	Uni-President Firms Corporation	\$287,000	\$2,870
3	Giant Manufacturing Co. Ltd.	\$1,911,000	\$19,110
4	Synnex Technology International Corporation [41]	\$491,000	\$4,910
5	Delta Electronics	\$12,526,000	\$125,260
The sum of the profits from remanufactured furniture sales			\$33,640,790

authorities also need to actively promote the recycling of waste furniture. Through the implementation of this strategy, it is bound to improve the benefits of recycling waste furniture and reduce garbage.

(iii) Carbon dioxide reduction: the recycling of waste wood per kilogram can reduce the carbon dioxide emissions by approximately 3.0 kilograms. Currently, 3,880.05 metric tons of waste furniture is recycled, thereby reducing carbon dioxide (CO_2) emissions of 9,564,150 metric tons. If strategy three is implemented, it is expected to cause a reduction of 44,592,000 metric tons of CO_2 emissions, and 14,864 tons of recycled furniture would need to be repaired. Therefore, this strategy is certain to further enhance the environmental protection benefits, as presented in Table 8.

This study compares and evaluates the performance of the waste furniture C2C production programming model that has been proposed. As a result, the current situation in Taiwan has been highlighted, and production for Taiwan,

Table 8: The comparison of benefits between the current situation and strategy three.

Benefits	Current situation	Strategy 3	The improved benefit
The amount of recycled furniture	431,470	22,427,193	An increase in 10% recycled furniture
Profit	3,188.05	14,864	An increase in NTD 42,119.3 yuan
CO_2 reduction (ton)	9,564,150	44,592,000	A decrease in 956,430 tons of CO_2

Germany, and China has been planned. It has been found that different degrees of fuzzy information have an impact on C2C production planning. Therefore, the C2C production programming model can assist the waste furniture remanufacturing center by effectively carrying out the plan of waste furniture reuse to achieve the maximum profit.

5. Concluding Remarks

This study established the C2C waste furniture production programming model. The fuzzy theory was used to define the degree of product damage, the technical feasibility, etc. In this way, the optimal outputs of remanufactured furniture, coarsely crushed materials, and finely crushed materials for production programming were derived. The maximum profit for remanufactured furniture sales was also obtained. The situational simulations revealed that the qualitative information proposed had a significant impact on C2C waste furniture production programming. This study demonstrated through the statistical optimization and one-way analysis of variance that the results from different situations were optimal solutions. In this way, it was verified that the C2C production programming model could be used to obtain the maximum profit. This study filled the gaps from prior studies [9, 11].

In practice, this study proposed three strategies: (a) the authorities are obligated to buy a certain proportion of remanufactured furniture to newly produced furniture, (b) incentives should be given to encourage recycling waste furniture, and (c) firms are obliged to purchase remanufactured furniture as office furniture. These three strategies were analyzed to show that they had a strong potential to improve the benefits and profits of recycling waste furniture. Consequently, the recommendation was made that the authorities adopt and implement these three strategies. Additionally, C2C waste furniture production planning was explored by focusing on the waste furniture recycling center. In the future planning done by the TEPA, recycling plants in townships were also integrated to cause the resources to produce more benefits. Therefore, the recommendation is to consider how to better integrate the resources of recycling plants in the future to further improve the benefits of the C2C waste furniture production programming.

The findings regarding the relevant attributes for measuring environmental loads can be further incorporated into production programming to achieve sustainable development, such as the benefits from wood furniture recycling. If relevant attributes are taken into account when production programming is performed, comprehensive benefits would be achieved. This study has applied the 3Rs and proposes the 3 strategic types: compulsory procurement by the authorities, subsidy policy, and corporate social responsibility. All the strategies include the amount of recycled furniture, profit, and CO_2 reduction at the same time. The compulsory procurement by the authorities is most effective in terms of the amount of recycled furniture, profit, and CO_2 reduction that occurs. Hence, this study recommends that the TEPA creates regulation for the recycling process. This study also recommends that compulsory procurement by the authorities be based on the recycling subsidy proportion and on a higher recycling subsidy proportion with recycled green products being produced.

Data Availability

Data are available from the corresponding author for researchers who meet the criteria for access to confidential data.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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